Analysis of Thermal Bridges

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Hosted by Energy Systems Research Unit, University of Strathclyde
Agenda

- 0930 Thermal bridging
- 1000 Theoretical background
- 1100 Morning coffee
- 1115 Regulatory requirements
- 1230 Lunch
- 1330 Introduction to THERM 2
- 1400 Workshop exercise 1
- 1500 Afternoon coffee
- 1515 Workshop exercise 2
- 1630 Exercise feedback and wrap up
- 1700 Close
A thermal bridge is created when due to structural or geometrical interruptions to homogenous insulated construction elements a path is created that allows heat flow in addition to the one dimensional heat loss through the construction elements.

**Disadvantages:**
- Greater heat loss through fabric
- Localised cold spots on fabric elements
- Lower radiant temperature (lower thermal comfort)
- Condensation risk (mould hazard, maintenance)

**Importance:**
Proportion of heat loss through bridge increases as U values decrease.

**Table: Effect of Thermal Bridging on U value for a timber frame wall**

<table>
<thead>
<tr>
<th>Percentage of wall bridged</th>
<th>U value 89/25</th>
<th>U value 89/50</th>
<th>U value 89/89</th>
<th>U value 119/119</th>
<th>U value 140/140</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>15</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>20</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Examples

Example 1
Tie in Wall Construction

- Heat flow through the bridge material is not proportional to the cross section area of the material.
- Heat flow need not be perpendicular to lay of bridge.

Example 2
Structural beam below window
References

• More complicated EN ISO 13370 Thermal performance of buildings. Heat transfer via the ground. Calculation methods
• CIBSE Guide A – Environmental Design
• BRE IP 17/01 Assessing the effects of thermal bridging at junctions and around openings
• Conventions for calculating linear thermal transmittance and temperature factors. BRE 497
• MCRMA Technical Paper # 18. Conventions for calculating U-values, f-values and psi-values.
• Energy Savings Trust, Enhanced Construction Details
• Building Research Establishment – Approved certifier of design
Types of Thermal Bridges

1. Geometrical Thermal Bridges
   - Corner
   - Step
   - Junction between wall and balcony slab

2. Structural Thermal Bridges
   - Service opening
Types of Thermal Bridges

3. Systematic / repeated Thermal Bridges

- Wall ties
- Studs

4. Convective Thermal Bridges
Avoiding Thermal Bridges

Thermal barriers can be used to avoid thermal bridges

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Theoretical Overview

- One dimensional heat transfer
- Fourier’s equation for 1D and example and limitations
- Two dimensional heat transfer
- Fourier’s equation for 2D
- Application for 2D equation and limitations
- Transient conduction equation
- Overall transfer of heat
- Numerical solution and solvers
One dimensional heat transfer

Fourier’s Law of heat transfer:

\[ Q = kA \frac{\Delta T}{\Delta x} \]

- \( k \) = thermal conductivity (W/mK)
- \( T \) = Temperature (K or °C)
- \( x \) = length (m)
- \( Q \) = rate of heat loss (W)
- \( A \) = area (m\(^2\))

\[ \frac{Q}{A} = \text{heat flux (W/m}^2\text{)} \]

\[ \frac{\Delta T}{\Delta x} = \text{temperature gradient (K/m)} \]

\[ \frac{\Delta x}{k} = \text{thermal resistance (m}^2\text{K/W)} \]

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One dimensional heat transfer

Fourier’s Law of heat transfer – Example:

\[ Q = kA \frac{\Delta T}{\Delta x} \]

\[ T_1 = 2^0 C \]
\[ T_2 = 22^0 C \]
\[ \Delta x = 0.5m \]
\[ k = 1.2W / mK \]
\[ A = 10m^2 \]
\[ Q = 1.2 \times 10^2 \frac{20}{0.5} \]
\[ Q = 480W \]

\[ T_1 = 2^0 C \]
\[ T_2 = 22^0 C \]
\[ \Delta x = 0.5m \]
\[ k = 0.3W / mK \]
\[ A = 10m^2 \]
\[ Q = 0.3 \times 10^2 \frac{20}{0.5} \]
\[ Q = 120W \]
Overall heat transfer coefficient or U Value

\[ Q = UA \Delta T \]

\[ \frac{1}{U} = A \Sigma R = \frac{1}{h_{\text{conv, i}} + h_{\text{rad, i}}} + \sum \frac{x}{k} + \frac{1}{h_{\text{conv, e}} + h_{\text{rad, e}}} \]

Which layer is insulation?
# Standard Surface resistances

<table>
<thead>
<tr>
<th>Direction of heat flow</th>
<th>Upwards</th>
<th>Horizontal</th>
<th>Downwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside surface $R_{si}$</td>
<td>0.1</td>
<td>0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>Outside surface $R_{so}$</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

\[
Q = UA\Delta T
\]

\[
\frac{1}{U} = A\Sigma R = \frac{1}{h_{\text{conv}_i} + h_{\text{rad}_i}} + \sum \frac{x}{k} + \frac{1}{h_{\text{conv}_o} + h_{\text{rad}_o}}
\]

**Upto which tilt is a surface vertical?**

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Two dimensional heat transfer

- Transmission / conduction is one dimensional far from a corner but progressively shows two dimensional characteristics close to the corner.
- One dimensional analysis tends to overestimates heat loss in the case of a convex corner and underestimates in the case of a concave corner (if external dimensions are used).
- Two dimensional analysis has to be used in order to accurately predict heat transfer.

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When is three dimensional analysis required?

- 3D Ground heat transfer
- Significant Point thermal bridges
- Detailed analysis of individual (building) components
- Academic level results
Multi dimensional heat transfer

\[ Q = Q(x, y, z, t) \]

\[ Q = kA \frac{\partial T}{\partial x} \]

\[ \frac{\partial^2 T}{\partial x^2} = 0 \]

\[ \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \]

\[ \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \]

\[ \frac{\partial T}{\partial t} = \frac{k}{\rho C_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \frac{\dot{Q}}{\rho C_p} \]
Linear thermal transmittance

(ψ or psi value)

Transmission / conduction loss governed by U value

Transmission / conduction loss governed by psi value

\[ P_{1D} = \Sigma U A \Delta T \]

\[ \psi = \frac{P_{2D} - P_{1D}}{l \Delta T} \]
Linear thermal transmittance example

\[ \psi = \frac{Q_{2D} - U_A \times A_A \times \Delta T - U_B \times A_B \times \Delta T}{l \times \Delta T} \]
SAP calculations

\[ H_{TB} = \sum L \psi \]
\[ H_{TB} = y \sum A_{exposed} \]

1. Use \( y = 0.15 \) in absence of other information
2. Use \( y = 0.08 \) if all detailing conforms with Accredited Construction Details (Not available in SAP2009)
3. If \( y \) has been calculated from individual psi values use this value
4. If psi values are known for each junction use these. Psi values can be taken from table K1 or calculated from BR 497
## SAP Calculations

### Table K1: Values of $\Psi$ for different types of junctions conforming with Accredited Construction Details

<table>
<thead>
<tr>
<th>Junction detail in external wall</th>
<th>$\Psi$ (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel lintel with perforated steel base plate</td>
<td>0.50</td>
</tr>
<tr>
<td>Other lintels (including other steel lintels)</td>
<td>0.30</td>
</tr>
<tr>
<td>Sill</td>
<td>0.04</td>
</tr>
<tr>
<td>Jamb</td>
<td>0.05</td>
</tr>
<tr>
<td>Ground floor</td>
<td>0.16</td>
</tr>
<tr>
<td>Intermediate floor within a dwelling</td>
<td>0.07</td>
</tr>
<tr>
<td>Intermediate floor between dwellings (^a)</td>
<td>0.14</td>
</tr>
<tr>
<td>Balcony within a dwelling (^b)</td>
<td>0.00</td>
</tr>
<tr>
<td>Balcony between dwellings (^a)(^b)</td>
<td>0.04</td>
</tr>
<tr>
<td>Eaves (insulation at ceiling level)</td>
<td>0.06</td>
</tr>
<tr>
<td>Eaves (insulation at rafter level)</td>
<td>0.04</td>
</tr>
<tr>
<td>Gable (insulation at ceiling level)</td>
<td>0.24</td>
</tr>
<tr>
<td>Gable (insulation at rafter level)</td>
<td>0.04</td>
</tr>
<tr>
<td>Corner (normal)</td>
<td>0.09</td>
</tr>
<tr>
<td>Corner (inverted)</td>
<td>-0.09</td>
</tr>
<tr>
<td>Party wall between dwellings (^a)</td>
<td>0.06</td>
</tr>
</tbody>
</table>
1. Use $y=0.15$ in absence of other information:

$$H_{TB} = 0.15 \times 12 = 1.8$$

2. Use $y=0.08$ if all detailing conforms with Accredited Construction Details \textbf{(Not available in SAP2009)}

$$H_{TB} = 0.08 \times 12 = 0.96$$

3. If $y$ has been calculated from individual psi values use this value
SAP calculations example

4. If psi values are known for each junction use these.

\[ H_{TB} = \Sigma L \psi \]

\[ H_{TB} = 0.16 \times 4 + 0.14 \times 4 + 0.09 \times 3 + 0.09 \times 3 = 1.74 \]
SBEM calculations example
SBEM calculations example

Loads vs Thermal Bridges

Total load vs thermal bridges

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2D heat transfer software THERM

Free software from LBNL USA

http://windows.lbl.gov/software/therm/therm.html

Version 6.3 (September 2010)
2D heat transfer software THERM

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Temperature profile
THERM 2 Solution Procedure

A PC program for analysing 2D heat transfer through building products

Input data
Geometry
Material properties
Boundary conditions

Automatic mesh generation

Heat transfer analysis

Error estimation
OK
Not OK

Mesh refinement

Converged solution
Calculating the psi value

Use the modelling U value $U^\prime$ instead of U value.

The modelling U value $U^\prime$ includes any effects of repeated thermal bridges in the construction of flanking elements.
Worked Example Eaves detail (BRE 497 Exercise)

Boundary conditions

- **20 °C & 0.13 m²K/W**
- **20 °C & 0.10 m²K/W**
- **1 °C & 0.10 m²K/W**
- **0 °C & 0.13 m²K/W**
- **0 °C & 0.04 m²K/W**

Timber joists and rafters @ 400mm c/c. Joists are 100mm deep and 38mm wide. Rafters are 150mm deep and 38mm wide.

- **250mm mineral wool with thermal conductivity of 0.037W/m·K**
- **55mm firestop with thermal conductivity of 0.045W/m·K**
- **12.5mm plasterboard with thermal conductivity of 0.21W/m·K**
- **115mm mineral wool with thermal conductivity of 0.037W/m·K**

10mm plywood sheathing with thermal conductivity of 0.13W/m·K

55mm cavity

103mm brick with thermal conductivity of 0.77W/m·K

Ventilated soffit
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2D model section with materials and dimensions

- Mineral wool 250mm, 0.037W/mK
- Mineral wool 115mm, 0.037W/mK
- Fire stop 55mm, 0.045W/mK
- plasterboard 12.5mm, 0.21W/mK
- Plywood 10mm, 0.13W/mK
- brick 103mm, 0.77W/mK
- Air cavity 55mm, 0.306W/mK

100mm 800mm 311mm 837mm

Wood, 0.13W/mK

37mm

311mm
BRE 497 Roof junction boundary condition conventions (Not CEPH conventions)

Roof eaves (insulated at ceiling)

- It is usual to take $T_i=20^0C$ and $T_e=0^0C$
- A heat balance between $U_R'$ and $U_C'$ can give $T_L$
- For ventilated ceilings $T_L \sim T_e$ but ventilation component of $U_R'$ is not generally known. $T_L$ is taken as $1^0C$ for such cases.
- $R_{se}$ of 0.10m²K/W is taken for the upper surface of the loft space.

$\psi = L - l_w \times U_W' - l_c \times U_C'$
Boundary conditions

- 1° C @ 0.1 m²K/W
- 20° C @ 0.1 m²K/W
- 0° C @ 0.13 m²K/W
- Adiabatic
- 20° C @ 0.13 m²K/W
- 0° C @ 0.04 m²K/W
- Adiabatic
Some information held in the model (e.g. material detail) may not be present in THERM libraries (repository of information held at system level and not model level). For such cases this message is displayed with the option to update libraries from the model. Choose No and Use properties in THERM file.
Overcoming reduced mouse functionality

By default, some versions of MS Windows operating systems do not support some mouse actions within the THERM software, so it is recommended to change the settings. This is done as follows:

1. Close THERM
2. Right-click on the THERM icon (on desktop or from Start > programs > LBNL software > THERM)
3. Click on properties
4. In the compatibility tab, check disable visual themes and then click OK

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Important notes

A THERM model contains the following three items (preferably in the same order) Geometry (dimensions and shape) Material specification (thermal conductivity and emissivity) Boundary condition (surface temperature and heat transfer coefficient)

A THERM model does not have overlapping polygons. It is productive to do it right the first time.
Basic tasks (15~20min)

Task 1: Play with F7, ctrl+F7 and right mouse click
Task 2: Double click on one of the polygons
Task 3: Double click on one of the outside edges of the shape
Task 4: Inspect the dimensional information given in the status bar (at the bottom of the window)
Task 5: Use the tape measure to measure various lengths

Task 6: Use sticky keys to permanently select the tape measure (click sticky keys followed by tape measure)
Task 7: Answer questions 1 to 5 on the worksheet
The mesh parameter determines the maximum element size in the mesh. The larger the mesh parameter, the smaller the maximum size. When modeling cross sections with very fine detail, you may need to increase this setting. Increasing the mesh parameter also increases the number of elements and, as a result, increases the time required to generate the mesh. Lower numbers produce coarser mesh, higher numbers produce a finer mesh. (Note: The mesh parameter is based on geometry, and if a fine detail in the cross section is not being meshed to the level you think is necessary, and increasing the mesh parameter doesn’t change this, you should check the Run Error Estimator check box and the mesh will be refined in this region if it is necessary.) Default: 6.

Measure of error in heat flux calculated for each element. If less than value shown in U-factors results reduce this number.

Number of times mesh will be refined when run error is on

10211 compliance values are Quad Tree = 8, Error = 2% and 10 iterations respectively
Simulation and results analysis

Task 8  Simulate either by pressing F9 or the simulate icon
Task 9  Toggle results by clicking the show results icon
Task 10 Inspect grid by switching colour off (view > material colours) and (calculation > display options > finite element mesh)
Task 11 View the various types of results available
Task 12 Do Q6 on worksheet (view > temperature at cursor)
Isotherms
Isotherms
Temperature
Calculation of f value

Minimum temperature = 17.9°C

Typical safe value for dwellings is \( f > 0.75 \) \([\text{MCRMA\_TP18}]\)

Minimum recommended temperature = 12.6°C \([\text{PHI}]\)

\[
f_{\text{min}} = \frac{T_{\text{int-surf-min}} - T_{\text{ext}}}{T_{\text{int-min}} - T_{\text{ext}}}
\]

\[
f_{\text{min}} = \frac{17.9 - 0}{20 - 0}
\]

\[
f_{\text{min}} = 0.895
\]
**Simple example using THERM**

<table>
<thead>
<tr>
<th></th>
<th>R_si</th>
<th>R_so</th>
<th>H_si</th>
<th>H_so</th>
<th>λ</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface resistance</td>
<td>Surface resistance</td>
<td>Surface HTC (film coefficient)</td>
<td>Surface HTC (film coefficient)</td>
<td>Conductivity</td>
<td>thickness</td>
</tr>
<tr>
<td></td>
<td>m²K/W</td>
<td>m²K/W</td>
<td>W/m²K</td>
<td>W/m²K</td>
<td>W/mK</td>
<td>mm</td>
</tr>
<tr>
<td>Material A</td>
<td>0.13</td>
<td>0.04</td>
<td>7.69</td>
<td>25</td>
<td>0.51</td>
<td>200</td>
</tr>
<tr>
<td>Material B</td>
<td>0.1</td>
<td>0.04</td>
<td>10</td>
<td>25</td>
<td>1.4</td>
<td>200</td>
</tr>
</tbody>
</table>
Materials library

Select Libraries > material library

The two parameters of importance are Material name and Conductivity.

Emissivity is used in radiation calculations and can be safely ignored for most psi value calculations. For air cavities select Frame Cavity and use default values.

Detailed radiation calculations are out of the scope of the current exercise.
### Defining new materials

**Task** Define new material called Material\_A with conductivity of 0.51W/mK as follows. From the materials library select New > give material name and conductivity 0.51 > Close (there is no need to save)

**Task** Similarly define Material\_B with conductivity of 1.4W/mK. Also give it a different colour by pressing the colour button

<table>
<thead>
<tr>
<th></th>
<th>R_si</th>
<th>R_so</th>
<th>H_si</th>
<th>H_so</th>
<th>λ</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface resistance</td>
<td>Surface resistance</td>
<td>Surface HTC (film coefficient)</td>
<td>Surface HTC (film coefficient)</td>
<td>Conductivity</td>
<td>thickness</td>
</tr>
<tr>
<td>Material A</td>
<td>0.13</td>
<td>0.04</td>
<td>7.69</td>
<td>25</td>
<td>0.51</td>
<td>200</td>
</tr>
<tr>
<td>Material B</td>
<td>0.1</td>
<td>0.04</td>
<td>10</td>
<td>25</td>
<td>1.4</td>
<td>200</td>
</tr>
</tbody>
</table>

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Boundary Condition library

Select Libraries > boundary condition library

For psi value calculations the simplified model is sufficient. Data inputs include temperature and film coefficient (reciprocal of film resistance)

<table>
<thead>
<tr>
<th>Direction of heat flow</th>
<th>Inside $R_{si}$</th>
<th>Inside co-eff</th>
<th>Outside $R_{so}$</th>
<th>Outside co-eff</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\uparrow$</td>
<td>0.10</td>
<td>10.00</td>
<td>0.04</td>
<td>25.0</td>
</tr>
<tr>
<td>$\leftrightarrow$</td>
<td>0.13</td>
<td>7.69</td>
<td>0.04</td>
<td>25.0</td>
</tr>
<tr>
<td>$\downarrow$</td>
<td>0.17</td>
<td>5.88</td>
<td>0.04</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Note that surface orientation is normal to heat flow e.g. horizontal heat flow occurs at walls which are vertical.
Defining new boundary conditions (BC)

Task 14  Define new BC called Internal_wall with film coefficient of 7.69 W/m$^2$K and temperature of 20$^0$C as follows: Libraries > boundary condition library > new > internal_wall > 20$^0$C & 7.69 W/m$^2$K > close

Task 15  Define the following BC (You may wish to give these different colours)

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
<th>Film coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Ceiling</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Note that for a floor junction the heat transfer coefficient for downwards heat flow will be used (5.88 W/m$^2$K). The external part of the floor slab has a convective coefficient of 0 (no air flow under it) but CEPH reduction factor can be input following the ground sheet in the PHPP.
Inputting geometry

Set snap on:
Options > preferences > snap settings > Snap to grid – grid setting of 20mm,
Also set smart snap on and make sure snap to vertical and horizontal is on

Draw section A (vertical or wall)
Select the rectangle button and VERY CAREFULLY single click anywhere on the white background of the drawing area (the mouse must not move after you have clicked). Now press the following keys
1000 [vertical length of this element]
down arrow [command to draw 1000mm downwards from mouse position]
200 [horizontal length of element / thickness of wall]
left arrow
return

Similarly draw section B (roof)
Make sure make the initial mouse click exactly at the vertex of the previous rectangle, otherwise overlapping or geometrically separated rectangles may result. (Snap to grid ensures this)

More complex polygons can be made with the polygon button
Model Attribution (geometry)

Select roof and define it to be material B using the drop down menu, similarly define the wall to be material A.
Model Attribution (BC)

1. Click on the draw BC icon, this makes BC around the perimeter of the model and attributes every BC to be adiabatic.

2. Now select each of the boundaries in turn and attribute as relevant

   - Exterior
   - ceiling
   - Internal wall
   - Adiabatic (leave as is)
   - Adiabatic (leave as is)

3. The model should simulate (if not then copy from delegate pack)
Calculating the psi value I

U factor is the heat flow through one meter depth of the model. This is used to calculate the psi value as follows:

\[ \text{Psi value} = \text{U factor} \times \text{length of 2D model} - \text{sum of U value} \times \text{length of flanking element} \]

Associate a U factor with all internal surfaces of the model as follows:

1. Create a new U factor: Libraries > U factor names > Add > “unique name” e.g. Simple_internal_UFactor > close
2. Select the two internal BC: press the shift key while carefully clicking on the two surfaces > press return and the U Factor window should appear
3. Select the appropriate U Factor name and press OK
4. Rerun simulation
5. Press the U factor icon

6. The product of U factor and length will be used in the formula

\[
\text{Psi} = \text{U factor} \times \text{length of 2D model} - \text{sum of U values} \times \text{length of flanking element}
\]

Note that changing the projected direction changes both U factor and length but the product does not change.

This value should be less than maximum allowed error norm (see slide on technical details)

Note that changing the projected direction changes both U factor and length but the product does not change.
Calculating the psi value III

Psi value = \( U \) factor \( \times \) length of 2D model – sum of \( U \) value \( \times \) length of flanking element

\[
\frac{1}{U} = R_{SI} + \frac{\text{thickness}}{\text{conductivity}} + R_{SO}
\]

\[
\frac{1}{U_A} = 0.13 + \frac{0.2}{0.51} + 0.04
\]

\[
\frac{1}{U_A} = 0.5622 \rightarrow U_A = 1.78W/m^2K
\]

\[
\frac{1}{U_B} = 0.1 + \frac{0.2}{1.4} + 0.04
\]

\[
\frac{1}{U_B} = 0.2829 \rightarrow U_B = 3.54W/m^2K
\]

Psi value = \((6.3814\times0.8) - (1.78\times1) - (3.54\times1.2) = -0.923W/mK\)

<table>
<thead>
<tr>
<th>( R_{si} )</th>
<th>( R_{so} )</th>
<th>( H_{si} )</th>
<th>( H_{so} )</th>
<th>( \lambda )</th>
<th>( T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface resistance</td>
<td>Surface resistance</td>
<td>Surface HTC (film coefficient)</td>
<td>Surface HTC (film coefficient)</td>
<td>Conductivity</td>
<td>thickness</td>
</tr>
<tr>
<td>m²K/W</td>
<td>m²K/W</td>
<td>W/m²K</td>
<td>W/m²K</td>
<td>W/mK</td>
<td>mm</td>
</tr>
<tr>
<td>Material A</td>
<td>0.13</td>
<td>0.04</td>
<td>7.69</td>
<td>25</td>
<td>0.51</td>
</tr>
<tr>
<td>Material B</td>
<td>0.1</td>
<td>0.04</td>
<td>10</td>
<td>25</td>
<td>1.4</td>
</tr>
</tbody>
</table>
PassivHaus construction example AWm02 DAm02
Construction AWm02

**AWm02:**
1. Fibre cement panels
2. Rear ventilation b/w upright aluminium lathes, insect screen
3. Open diffusion wind sealing with windproof glued joints
4. Wood shuttering w. 1mm gaps b/w boards
5. Mineral wool b/w C posts
6. Brick chipping concrete wall (clay blocks)
7. Lime cement plaster

<table>
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<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>λ (W/mK)</td>
<td>0.13</td>
<td>0.04</td>
<td>0.27</td>
<td>0.8</td>
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<tr>
<td>h (mm)</td>
<td>24</td>
<td>300</td>
<td>200</td>
<td>15</td>
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U=0.12W/m²K
Construction DAm02

**DAm02:**
1. PE seal mechanically bonded
2. PP fleece
3. Wood shuttering
4. Ventilated cavity
5. Open diffusion sheet, welded airtight
6. Wood shuttering
7. Mineral wool b/w C sections
8. Reinforced concrete
9. Filler

<table>
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<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>$\lambda$ (W/mK)</td>
<td>0.13</td>
<td>0.04</td>
<td>2.1</td>
<td>Ignore</td>
</tr>
<tr>
<td>$h$ (mm)</td>
<td>24</td>
<td>400</td>
<td>200</td>
<td>Ignore</td>
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$U=0.10\text{W/m}^2\text{K}$
Boundary Conditions and Dimensions

- **PH Sheltered Roof**
  - $T=0^\circ C$, $H_c=10\text{ W/m}^2\text{K}$

- **PH Sheltered wall**
  - $T=0^\circ C$, $H_c=7.69\text{ W/m}^2\text{K}$

- **PH Ceiling**
  - $T=20^\circ C$, $H_c=10\text{ W/m}^2\text{K}$

- **PH Internal wall**
  - $T=20^\circ C$, $H_c=7.69\text{ W/m}^2\text{K}$
U factors

Define these two surfaces to have a U factor and call it PHExample.

Now simulate and calculate U factor * length

\[ 0.285 \times 1.376 = 0.3922 \]

Use the model provided if you are not satisfied with the results.
Psi value

Psi value = U factor * length of 2D model
− sum of U values * length of flanking elements

Psi value = 0.3922 - 0.12x2 - 0.10x2.324 = -0.0802W/mK

Assumptions built into model:

• C sections have not been included
• Ceiling filler has not been included
Miscellaneous notes

It is possible to import images and *.dxf files as underlays (File > underlay)

If a space is completely enclosed by polygons then the void can be filled by a polygon (Draw > fill void)
Worksheet

• Q1. What is the function of the F7 key, the right mouse button and control + right mouse button?
  
  F7 = ________________
  
  right click = ________________
  
  control + right click = ________________

• Q2. What is the thermal conductivity of the materials called “BRE 497 – fire stop” and “BRE 497 – plasterboard”?
  
  BRE 497 fire stop = ________________
  
  BRE 497 plasterboard = ________________

• Q3. Which surface has a temperature of $1^0C$? Is the heat transfer coefficient of the external wall correct? Which two boundaries are adiabatic and why?

  ____________________________________________________________
  ____________________________________________________________

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Worksheet

• Q4. What are the dimensions of the rectangle representing roof insulation?

  length = ________________  breadth = ________________

• Q5. What are the dimensions of the trapezium at the junction of the wall and roof? (mark on image)

• Q6. What is the minimum internal surface temperature for this model?

  Minimum internal temperature = ________________
Mathematical proof of psi values from U factors

(Not required for generating psi values from THERM)

\[ \psi L \Delta T = P_{2D} - P_{1D} \]

\[ \psi = \frac{P_{2D} - P_{1D}}{L \Delta T} \]

\[ U_f L \Delta T - \Sigma U A \Delta T \]

\[ = \frac{U_f L \Delta T - \Sigma U A \Delta T}{L \Delta T} \]

\[ = \frac{U_f L - \Sigma U L \times 1}{1} \]

\[ = U_f L - \Sigma U L \]